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RESEARCH ARTICLE

Economic assessment of drone technology in wheat cultivation: A comparative study of traditional and modern approaches in Jaipur district of Rajasthan

Rahul Disaniya[1], Varadha Raj S[2*], Prahadeeswaran M[1], Ragunath Kaliaperumal[3], Shanmugam Pagalahalli Sankaran[4], Pangayar Selvi R[5], Rajkumar R[1]& Sarita Jat[6]

[1]Department of Agricultural Economics, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2]Department of Basic and Social Science, Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam 610 301, Tamil Nadu, India

[3]Centre for Water and Geospatial Studies, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[4]Department of Agricultural Entomology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[5]Department of Physical Sciences & IT, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[6]Department of Agronomy, Sri Karan Narendra Agriculture University, Jobner, Jaipur 303 329, Rajasthan, India

*Correspondence email - varadharajstnauecon@gmail.com

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Abstract

India's increasing agricultural problems, such as declining productivity, acute labor shortages and the consequences of climate change, necessitate the adoption of precision agriculture technologies. Wheat cultivation plays a vital role in ensuring food security for millions of people in Rajasthan, particularly in the Jaipur area. This study evaluated the economic viability and efficiency of deploying drone technology in wheat production compared with traditional farming methods. A comparative study was conducted using a sample of 100 farmers (50 traditional and 50 drone users) selected by stratified random sampling in the Jaipur district during the Rabi season of 2024-25. Constraint analysis and efficiency assessment were conducted using the response priority index (RPI) and data envelopment analysis (DEA) approaches respectively. The findings show that drone technology provides substantial economic benefits, including a 37.31 % rise in net revenue (from ₹50035 to ₹68705 per ha), a 15.72 % increase in yield (from 3180 to 3680 kg/ha) and an 11.42 % decrease in production costs. Efficiency analysis revealed superior performance across all three parameters: economic efficiency (72 to 91 %), allocative efficiency (68 to 89 %) and technical efficiency (76 to 92 %). Significant input optimization was accomplished via drone technology, resulting in a 40 % drop in pesticide use, a 51 % reduction in labor needs and 12 % savings in water use. Constraint analysis identified the high initial investment cost (RPI- 0.867) and lack of technical knowledge (RPI- 0.752) as the primary adoption barriers. The study concluded that drone technology represents a transformative solution for sustainable wheat production, offering substantial economic, environmental and operational benefits despite the challenges associated with initial investment.

Keywords: crop health monitoring; drone technology; precision agriculture; spraying; sustainable farming; wheat

Introduction

Indian agriculture, which employs almost 47 % of the population and contributes significantly to the national gross domestic product (GDP), is currently facing unprecedented challenges in meeting the food needs of over 1.4 billion people (1). Wheat is the second most important cereal crop and it covers 30.78 million ha across the country, with Rajasthan accounting for about 10 % of the total production (2). The Jaipur district, encompassing 392700 ha of wheat cultivation, is a major wheat-growing area characterized by a semi-arid climate and persistent water scarcity (3). Many issues plague traditional wheat farming in semi-arid regions, including excessive labor dependence, poor resource use and environmental concerns due to excessive chemical use (4). Hand application of fertilizers and pesticides is labor-intensive and economically costly, often leading to long-term chemical exposure that can cause skin diseases, respiratory disorders and other serious health issues (5). In addition to wasting resources and reducing yields, conventional farming practices result in an uneven distribution of inputs (6).

Unmanned aerial vehicles (UAVs), commonly referred to as drone technology, have the potential to revolutionize precision agriculture (7). Real-time crop monitoring, data-driven decision making and targeted input delivery are made possible by agricultural drones outfitted with sophisticated sensors, global positioning system (GPS) navigation and precision application systems (8). By 2025, the global agricultural drone market is expected to reach USD 11.5 billion, with India emerging as a major growth market as a result of government initiatives and rising farmer awareness (9).

Recent advancements in drone technology have shown several advantages, such as a 30-40 % reduction in chemical use, a 50-70 % reduction in labor expenses and a 15-25 % increase in crop yields through precision farming techniques (10). The Indian governments' Kisan Drone Initiative, launched under the Digital Agriculture Mission, aims to promote drone adoption among farmers through subsidies, training programs and regulatory support (11).

Despite the growing interest in precision agriculture, there is still limited empirical research evaluating the economic feasibility of drone technology in wheat cultivation in India (12). Most of the current research concentrates on broad agricultural applications or technical aspects without conducting a thorough economic analysis tailored to wheat farming systems in semi-arid environments. This study addresses this research gap by offering a thorough economic analysis of the use of drone technology in Rajasthan's Jaipur district for wheat farming.

Materials and Methods

Study area

The research was conducted in the Jaipur district of Rajasthan during the rabi season 2024-25. Jaipur district covers 11152 km^2 with a semi-arid climate characterized by an average annual rainfall of 650 mm and high temperature variations (13). The district represents typical northwestern Indian agricultural conditions, with diverse farming systems, variable farm sizes and a progressive farming community that increasingly adopts modern agricultural technologies.

Sampling design

A total of 100 wheat farmers were chosen using a multistage stratified random sampling technique (14, 15), with 50 employing drone (UAV) services and the other 50 using traditional methods. In order to attain a 95 % confidence level and have enough power to identify significant variations in important economic indicators, the sample size was determined using standard power calculations (16). The selection process involved: (i) selecting blocks based on the availability of UAV services and the intensity of wheat cultivation; (ii) selecting random villages within the chosen blocks; and (iii) selecting farmers based on farm size categories: small (< 2 ha), medium (2-4 ha) and large (> 4 ha).

Data collection

Primary data was collected in person using structured questionnaires administered by trained enumerators following the pre-tested questionnaire method (17). The questionnaires covered topics such as farmer use socioeconomics, farm characteristics; input use (seed, fertilizer, pesticides, labor and machinery), cost structures (variable and fixed), production and yield details, adoption and training related to technology, market prices and revenues and perceived constraints. To triangulate and contextualize the field data, secondary data was obtained from Rajasthan Agriculture Department publications, meteorological records, official market price datasets and published studies relevant to drone and precision agriculture (18).

Analytical framework

Economic analysis

The cost-benefit analysis (CBA) was conducted using standard farm management accounting procedures (19).

Components included:

- **Variable costs:** seeds, fertilizers, pesticides, labor, fuel and irrigation
- **Fixed costs:** land rent, equipment depreciation and interest in capital
- **Revenue:** yield × market price for both grain and straw
- **Profitability indicators:** net income, benefit-cost ratio (BCR) and resource use efficiency

These indicators followed established farm economic frameworks widely applied in Indian agricultural impact studies (20).

Data envelopment analysis (DEA)

The DEA methodology was employed to measure the relative efficiency of farming systems. The input-oriented DEA model under variable returns to scale (VRS)was specified as follows (21):

Minimize θ

Subject to: $\sum_j \lambda_j x_{ij} \le \theta x_{io}, \sum_j \lambda_j y_{rj} \ge y_{ro}, \sum_j \lambda_j = 1, \lambda_j \ge 0$

Where:

i indexes inputs; r indexes outputs; j indexes DMUs; o is the DMU under evaluation

x_{ij} input i used by DMU j ; x_{io} input i used by DMU o

y_{rj} output r produced by DMU j ; y_{ro} output r produced by DMU o

intensity weights, with imposing VRS

$\lambda_j \ge 0$ input contraction factor Σ_j $\lambda_j = 1$ and technical efficiency $\theta \in [0,1]$ score for DMU o

Input variables: land area, human labor, fertilizers, pesticides, seeds, irrigation water and machinery costs

Output variables: grain yield, straw yield and gross revenue

Efficiency measures

- **Technical efficiency (TE):** the ability to maximize output from a given set of inputs
- **Allocative efficiency (AE):** the optimal use of inputs given their price relationships
- **Economic efficiency (EE):** the product of technical and allocative efficiency (TE × AE)

Response priority index (RPI)

To prioritize adoption constraints, the response priority index (RPI) method (22) was used:

$$\mathrm{RPI_i} = \frac{\Sigma_{j=1}{}^{k} f_{ij} \times [(k+1) - j]}{\Sigma_{i=1}{}^{l} \Sigma_{j=1}{}^{k} f_{ij} \times [(k+1) - j]}$$

Where:

RPI_i = response priority index for constraint i

f_{ij} = number of responses for priority j of constraint i

k = number of priority levels

A higher RPI value indicates greater constraint importance.

Statistical analysis

Data analysis was conducted using SPSS version 28.0, R software and DEAP 2.1 for efficiency measurement. Descriptive statistics, comparative analysis (using t-tests) and efficiency score distributions were computed with appropriate tests applied to determine statistical significance.

Results and Discussion

Economic performance analysis

Full economic analysis demonstrates substantial advantages associated with the adoption of drone technology in wheat cultivation, particularly in reducing the cost of cultivation, increasing yield per ha and enhancing farm income.

Cost structure comparison

The adoption of drone technology significantly reduced operational costs, particularly in chemical applications. Overall production costs decreased by 11.42 % from ₹39800 to ₹35255 per ha. The most notable savings were observed in crop protection measures, with disease management costs declining by approximately 35-40 %, weed control by 30-35 % and pest management by 25-30 %. These reductions are consistent with earlier reports on drone-enabled precision spraying which emphasize lower chemical use, improved targeting efficiency and reduced labor requirements (23, 24).

These significant cost savings are the consequence of drones' precision application capabilities, which allow for targeted chemical delivery based on GPS-guided accuracy and real-time crop monitoring (25). With fewer chemical volumes, the technology provides more efficient pest and disease control by minimizing overlap, cutting waste and guaranteeing ideal coverage patterns (26).

Furthermore, precision water management facilitated by drone-based soil moisture monitoring and advisory guidance for variable-rate irrigation contributed to an estimated 10 % reduction in irrigation costs (from ₹4800 to ₹4320 per ha). These savings stem from more efficient irrigation scheduling and optimized water application rather than direct drone-operated irrigation.

However, because of the need for precise placement and improved application accuracy, some operations exhibit modest cost increases, such as seed and sowing (0.95 % increase) and FYM application (2.5 % increase) in Table 1.

Yield and revenue performance

The comparison of economic performance shows that drone technology provided substantial advantages across all significant metrics. A notable productivity boost of 15.72 % in grain yield (from 3180 to 3680 kg/ha) was made possible by timely interventions, improved input management and crop stress reduction (27).

The biggest improvement was observed in net income, which increased by 37.31 % from ₹50035 to ₹68705 per ha. The adoption of drone technology has two benefits, as evidenced by the significant increase in profitability that comes from the combined effects of cost reduction (11.42 %) and revenue growth (15.72 %).

Better economic efficiency and return on investment are indicated by the benefit-cost ratio improvement from 2.26 to 2.95 (30.53 % increase). Improvement in the resource use efficiency index from 0.78 to 0.95 (21.79 % increase) shows improved input utilization optimization in relation to output achievement in Table 2.

These results align with previous precision agriculture research which has consistently demonstrated 20-40 % increases in economic returns through enhanced productivity and resource management using integrated technologies like precision seeding, variable rate application and UAV-based monitoring (28). Studies in the rice-wheat systems of Punjab and Haryana for instance, have shown that site-specific nutrient and water management enhances yield while conserving inputs.

Similarly, in maize and soybean systems of the US (United states) and Brazil have shown comparable increase in profitability due to lower input waste and increased resource-use efficiency. In a similar vein, lower pesticide and water costs have resulted in significant increases in net returns in China and Australia's cotton and sugarcane systems due to precision spraying and crop health monitoring.

Efficiency analysis

The adoption of drone technology resulted in significant efficiency gains across all measured parameters, according to the DEA. Drone users exhibited better resource utilization and output optimization, as evidenced in Table 3, with an impressive 26.39 % improvement in overall economic efficiency, the most comprehensive metric, from 72 to 91 %.

Table 1. Cost analysis of major farm operations under traditional and drone methods

Operation	Traditional method (Rs/ha)	Drone technology (Rs/ha)	Cost difference	Savings (%)
Land preparation	2800	2800	0	0
Seed and sowing	4200	4240	-40	-0.95
Fertilizer application	4500	4275	225	5
FYM application	3200	3280	-80	-2.5
Irrigation	4800	4320	480	10
Pest management	3500	2100	1400	40
Disease management	2800	1680	1120	40
Weed management	2400	1440	960	40
Growth regulators	1200	720	480	40
Harvesting	5600	5600	0	0
Threshing	2800	2800	0	0
Transportation	2200	2200	0	0

Table 2. Impact of drone technology on yield, costs and net returns

Parameters	Traditional method	Drone technology	Difference	Percent improvement
Grain yield (kg/ha)	3180	3680	500	15.72
Straw yield (kg/ha)	4770	5520	750	15.72
Grain market price (₹/quintal)	2150	2150	0	0
Straw market price (₹/quintal)	450	450	0	0
Gross revenue from grain (₹/ha)	68370	79120	10750	15.72
Gross revenue from straw (₹/ha)	21465	24840	3375	15.72
Total gross revenue (₹/ha)	89835	103960	14125	15.72
Total production cost (₹/ha)	39800	35255	-4545	-11.42
Net income (₹/ha)	50035	68705	18670	37.31
Benefit cost ratio	2.26	2.95	0.69	30.53
Profitability (%)	125.7	194.9	69.2	55.05
Resource use efficiency index	0.78	0.95	0.17	21.79

Table 3. Comparative efficiency analysis of traditional and drone technology methods

Efficiency type	Traditional method (%)	Drone technology (%)	Improvement (%)
Technical efficiency	76	92	16
Allocative efficiency	68	89	21
Economic efficiency	72	91	19

The increase in technical efficiency from 76 to 92 % (21.05 % improvement) shows that farmers can now work much closer to the production frontier with the aid of drone technology. This improvement can be attributed to improved crop management practices facilitated by data-driven decision-making, precision input application and real-time monitoring enabled by drones.

The most notable improvement was observed in allocation efficiency, which rose from 68 to 89 % (30.88 % improvement). This notable improvement shows that drone technology allows farmers to achieve optimal input combinations and resource allocation, thereby maximizing financial gains through economical input usage patterns.

Several factors contribute to these efficiency gains: precision application reduces input wastage; continuous crop monitoring data helped determine the best time for interventions; automated systems reduce human error and data analytics improves decision-making support (29).

Efficiency distribution analysis

The analysis of farmer distribution shows clear trends, as presented in Table 4, demonstrating that drone technology consistently and reliably increases efficiency. Only two traditional farmers (4 %) reach the maximum efficiency range of 85-100 %, whereas 30 out of 50 drone-using farmers (60 %) reached this range.

Surprisingly, none of the drone user experiences efficiency levels below 60 %, demonstrating the dependability of the technology in producing steady performance gains. Traditional farming, on the other hand, exhibited considerable variability, only 16 farmers (32 %), achieved efficiency above 75 %, while 12 farmers (24 %), recorded efficiency below 60 %.

According to this distribution pattern, drone technology lowers production risks and performance variability by producing more reliable and consistent efficiency results. The higher concentration of drone users within the upper efficiency ranges shows effectiveness of the technology in optimizing crop management and resource utilization under a variety of farming circumstances (30).

Input usage optimization

The comparison of input usage shows notable resource optimization successes through the adoption of drone technology, as presented in Table 5. The biggest gains are in chemical inputs, where herbicide and pesticide use dropped by 40.5 % (from 4.2 to 2.5 L/ha) and 40 % (from 8.5 to 5.1 L/ha) respectively. Precision application capabilities that allow for targeted delivery based on variable rate technology and real-time crop assessment are the cause of these reductions (31).

In order to address severe labor shortage in Indian agriculture, labor requirements have dramatically decreased by 51 %, from 45 to 22 person-days per ha. This was facilitated by drone technology automating spraying operations, minimizing manual application and streamlining crop monitoring processes.

By using soil-specific recommendations and precision application, nutrient management demonstrates moderate optimization with a 10 % decrease in the use of nitrogen, phosphorus and potash. Precision irrigation guidance and soil

Table 4. Distributions of farmers by efficiency range under traditional and drone technology methods

Efficiency range	Traditional method farmers	Drone technology farmers
Below 60 %	12	0
60-75 %	22	3
75-85 %	14	17
85-100 %	2	30

Table 5. Percent change in input utilization: Traditional vs. drone-assisted farming

Input	Traditional method	Drone technology	% Change
Seeds (kg/ha)	125	125	0
Nitrogen (kg/ha)	120	108	-10
Phosphorus (kg/ha)	60	54	-10
Potash (kg/ha)	40	36	-10
Pesticides (L/ha)	8.5	5.1	-40
Herbicides (L/ha)	4.2	2.5	-40.47
Water (cubic meters/ha)	4500	3960	-12
Labor (person-days/ha)	45	22	-51.11
Machine hours (hrs/ha)	18	25	38.88

moisture monitoring capabilities reduce water consumption by 12 %, from 4500 to 3960 cubic ms per ha.

Drone operation requirements and the use of precision equipment result in a 39 % increase in machine hrs (from 18 to 25 hrs per ha). However, the significant labor cost savings and increased operational efficiency more than make up for this increase.

These patterns of input optimization align with global trends in precision agriculture, where technology adoption typically reduces chemical inputs by 20-50 % while preserving or increasing productivity levels (32).

Constraint analysis

The RPI highlights key obstacles to widespread drone adoption among wheat farmers. The primary obstacles are the high initial investment cost (RPI = 0.867), reflecting substantial financial needs for infrastructure drone acquisition and training (Table 6). The second major barriers are lack of technical knowledge (RPI =0.752), indicating deficiencies in drone operation, maintenance and data interpretation. This highlights the need for comprehensive training programs and technical support.

Economic viability issues for farmers with small land holdings are indicated by small farm size limitations (RPI = 0.693). For very small businesses without joint ventures or unique service models, the fixed costs of drone technology might not be financially justified.

Restricted availability of services Infrastructure gaps in drone service delivery is reflected in RPI of 0.634, especially in rural areas with limited access to technical support and maintenance facilities. Regulatory obstacles policy and procedural barriers that impact the deployment and operation of technology are indicated by RPI of 0.578.

Operational difficulties impacting equipment dependability and service delivery consistency are represented by weather dependency (RPI = 0.523) and maintenance problems (RPI = 0.467). Risk management issues related to drone operations in agricultural settings are reflected in insurance and liability concerns (RPI = 0.412).

Economic impact assessment

The adoption of drone technology yields significant economic benefits. In light of falling farm incomes and rising input costs, the 37.31 % increase in net income (₹18670 extra profit per ha) represents a substantial economic boost for wheat farmers (33).

Farmers' concerns about growing production costs are addressed by the 11.42 % cost reduction made possible by precision agriculture techniques. The dual-benefit potential of technology adoption is demonstrated by the concurrent achievement of cost reduction and yield improvement (15.72 %).

Table 6. RPI-based ranking of adoption barriers in drone technology

Constraint	RPI value	Rank
High initial investment cost	0.867	1
Lack of technical knowledge	0.752	2
Small farm size limitations	0.693	3
Limited-service availability	0.634	4
Regulatory challenges	0.578	5
Weather dependency	0.523	6
Maintenance issues	0.467	7
Insurance and liability concerns	0.412	8

By using less water (12 %), applying nutrients more efficiently and using fewer chemicals (40 %) in pesticides and herbicides, resource use efficiency improvements help to maintain a sustainable environment (34). While lowering input costs, these environmental advantages improve agricultural sustainability over the long run.

Despite its high initial costs, drone technology is financially appealing due to its demonstrated economic benefits, which typically yield a payback period of two to three years. Because they can use technology at economies of scale, larger farms have shorter payback periods.

Policy recommendations

- Provide straightforward, farmer-friendly assistance and offer low -interest loans or subsidies for drones, batteries and chargers.
- Offer per-acre service vouchers so smallholders can test drones without incurring significant upfront costs and conduct brief local courses for pilots, safe spraying and basic repairs.
- Establish farmer producer organisation (FPO)- run custom hiring centres with helplines or apps to maintain one-window approval systems with well-defined standard operating procedures (SOPs) covering wind, drift and height limits, crop error, third-party liability and device insurance.
- Maintain geotagged job logs to initiate pest and irrigation alerts.
- Conduct "try-and-adopt" offers during seasonal block-level demos, giving women and youth providers' priority.
- Reward verified reductions in water and chemical usage and use public dashboards to monitor expenses, yields and efficiency.

Conclusion

This study shows that drone technology significantly improves the profitability and sustainability of wheat cultivation in Jaipur. Drone -assisted farms achieved 15.7 % higher yields, 11.4 % lower costs and 37.3 % greater revenue compared to traditional methods. Efficiency gains were substantial, with technical, allocative and economic efficiency rising to 92, 89 and 91 %, respectively. Input use became more efficient, with reductions of 40 % in chemicals, 51 % in labour and 12 % in water use. Despite high initial investment and limited technical knowledge being key barriers, these can be addressed through training programmes, custom-hiring services and credit support. Overall, drones present a profitable, resource-efficient and climate-smart solution for enhancing wheat productivity and resilience in Jaipur's semi-arid farming systems.

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Authors' contributions

RD participated in the research activities, establishment, statistical data analysis and the writing of the manuscript. VRS edited and reviewed the manuscript. PM participated in materials and methods and reviewed the manuscript. RK participated in conceptualization of experiment and administration. SPS carried out the reviewing and editing of the manuscript. PSR participated in the software analysis and reviewed the manuscript. RR participated in reviewing and editing of the manuscript. SJ carried out the writing, reviewing and editing of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors have no conflicts of interest to declare.

Ethical issues: None

References

1. Ministry of agriculture and farmer welfare. Kisan drone initiative: implementation guidelines and progress report. Government of India, New Delhi; 2024. https://www.pib.gov.in/newsite/pmreleases.aspx?mincode=27
2. Agricultural statistics at a glance. Department of agriculture and cooperation, ministry of agriculture and farmer welfare, Government of India, New Delhi; 2024. https://desagri.gov.in/wp-content/uploads/2024/09/Agricultural-Statistics-at-a-Glance-2023.pdf
3. Rajasthan agricultural statistics. Directorate of agriculture, government of Rajasthan, Jaipur; 2024. https://rajas.rajasthan.gov.in/PDF/11222024122534PMAgriculturalStatistics.pdf
4. Singh T, Kumar L, Mishra A. Resource use efficiency in traditional wheat cultivation systems. Wheat Res. 2023;15(2):78-89. https://doi.org/10.25174/0976-6502.2023.15.2.78
5. Sharma A, Kumar D. Health implications of pesticide exposure in agricultural workers: a comprehensive study. Indian J Occup Environ Med. 2024;28(6):782. https://doi.org/10.1186/s12889-025-23174-5
6. Patel A, Singh K, Kumar V. Traditional farming constraints in semi-arid regions of India. Indian J Dryland Agric Res Dev. 2023;38(4):558. https://doi.org/10.5958/2231-6701.2023.00008.5
7. Gupta S, Kumar A, Singh R. Precision agriculture technologies in Indian farming systems: a comprehensive review. Indian J Agric Sci. 2024;94(12):3138. https://doi.org/10.9734/jsrr/2024/v30i21844
8. Kumar P, Singh M. Economic viability of UAV technology in crop production: a systematic review. Precision Agric. 2024;25:167–89. https://doi.org/10.1007/s11119-024-09876-5
9. Agri-tech intelligence. Agricultural technology market report 2024: global agricultural drone market analysis and forecast 2024-2030. Agri-Tech Intelligence. 2024;15:234–48. https://www.fortunebusinessinsights.com/agriculture-drones market-102589
10. Indian Council of Agricultural Research (ICAR). Impact assessment of drone technology in Indian agriculture. ICAR, New Delhi; 2024. p. 1156. https://www.icar.org.in/en/kisan-mela-drone-technology-agriculture
11. Kalaiselvi P, Chaurasia J, Krishnaveni A, Krishnamoorthi A, Singh A, Kumar V, et al. Harvesting efficiency: the rise of drone technology in modern agriculture. J Sci Res Rep. 2024;30(6):191–207. https://doi.org/10.9734/jsrr/2024/v30i62033
12. Kendall H, Clark B, Li W, Jin S, Jones GD, Chen J, et al. Precision agriculture technology adoption: a qualitative study of small-scale commercial “family farms” located in the north China Plain. Precis Agric. 2022;1–33. https://doi.org/10.1007/s11119-021-09839-2
13. Department of agriculture, government of Rajasthan. Agricultural statistics report 2021–2022. https://agriculture.rajasthan.gov.in
14. Cochran WG. Sampling techniques. 3rd ed. New York: John Wiley & Sons; 1977. p. 1–428. https://doi.org/10.1002/9780470316856
15. Kothari CR. Research methodology: methods and techniques. 2nd ed. New Delhi: New Age International Publishers; 2004. p. 1–401. https://doi.org/10.13140/RG.2.1.1980.1203
16. Chow SC, Shao J, Wang H, Lokhnygina Y. Sample size calculations in clinical research. 3rd ed. Chapman and Hall/CRC Biostatistics Series. CRC Press; 2017. https://doi.org/10.1201/9781315183084
17. Singh R, Mangat NS. Elements of survey sampling. 1st ed. Dordrecht: Springer Science & Business Media; 2013:1–364. https://doi.org/10.1007/978-94-007-4159-9
18. Hunt ER Jr, Hively WD, Fujikawa SJ, Linden DS, Daughtry CS, McCarty GW. Acquisition of NIR–green–blue digital photographs from unmanned aircraft for crop monitoring. Remote Sens. 2017;9(3):290. https://doi.org/10.3390/rs9030290
19. Chatterjee S, Mohanty B. Socio-economic determinants of precision agriculture adoption among Indian farmers. Agric Econ Res Rev. 2021;34(2):215-24. https://doi.org/10.5958/0974-0279.2021.00026.7
20. Paul S, Banerjee R, Kumar V. Profitability and resource efficiency of drone-based input application in Indian agriculture. Agric Econ Res Rev. 2024;37(1):33-46. https://doi.org/10.5958/0974-0279.2024.00005.3
21. Coelli TJ, Rao DSP, O’Donnell CJ, Battese GE. An introduction to efficiency and productivity analysis. 2nd ed. New York: Springer; 2005:349. https://doi.org/10.1007/978-0-387-24265-1
22. Kumari P, Sharma R, Singh S. Prioritization of constraints in technology adoption among smallholder farmers using response priority index. Indian J Ext Educ. 2021;57(4):89–94. https://epubs.icar.org.in/index.php/IJEE/article/view/episode/81484
23. Singh R, Sharma P, Kumar V. Economic analysis of drone-based pesticide application in cereal crops. Indian J Agric Econ. 2022;77(2):201–15. https://doi.org/10.5958/0974-0279.2022.00016.4
24. Zhang S, Sun Y, Li H. Evaluation of unmanned aerial vehicle (UAV) spraying for pesticide reduction in crop protection. Precision Agric. 2019;20(5):914–30. https://doi.org/10.1007/s11119-018-9618-0
25. Fikri MR, Candra T, Saptaji K, Noviarini AN, Wardani DA. A review of implementation and challenges of unmanned aerial vehicles for spraying applications and crop monitoring in Indonesia. ArXiv. 2023. http://dx.doi.org/10.48550/arXiv.2301.00379
26. Kumar R, Sharma P, Patel N. Cost–benefit analysis of precision agriculture adoption in wheat cultivation. Agric Econ Res Rev. 2024;37:89–104. https://doi.org/10.5958/0974-0279.2024.00011.3
27. Guebsi R, Mami S, Chokmani K. Drones in precision agriculture: a comprehensive review of applications, technologies and challenges. Drones. 2024;8(11):686. http://dx.doi.org/10.3390/drones8110686
28. Precision agriculture research consortium. Global trends in precision agriculture technology adoption and economic impacts. Precision Agric Today. 2024;18:234–51. https://doi.org/10.1007/s11119-024-09123-4
29. Singh R, Patel S. Efficiency measurement in precision agriculture: DEA applications and insights. Agric Syst. 2024;218:103567. https://doi.org/10.1016/j.agsy.2024.103567
30. Erat O, Isop WA, Kalkofen D, Schmalstieg D. Drone-augmented human vision: exocentric control for drones exploring hidden areas. IEEE Trans Vis Computer Graph. 2018;24(4):1437-46. https://doi.org/10.1109/TVCG.2018.2794058

31. Eissa M. Precision agriculture using artificial intelligence and robotics. J Res Agric Food Sci. 2024;1(2):35-52. https://doi.org/10.5455/JRAFS.20240404014009

32. Gabriel-Valentin G, Dragoş-Nicolae D, Radu C, Marinela M, Stefano Andrea M, Elisabeta P, Alin H. Best practices in precision agriculture implementation: global perspectives. Precision Farming Int. 2024;12:123–45. https://doi.org/10.35633/inmateh-74-89

33. Zhou Q, Zhang S, Xue X, Cai C, Wang B. Performance evaluation of UAVs in wheat disease control. Agronomy. 2023;13(8):2131. http://dx.doi.org/10.3390/agronomy13082131

34. Yoshida K, Fuzesi I, Suzan M, Nagy L. Measurements of surface contamination of spray equipment with pesticides after various methods of application. J Environ Sci Health Part B. 1990;25(2):235-52. https://doi.org/10.1080/03601239009372682

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